(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 793 314 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
28.03.2001 Bulletin 2001/13

(51) Int Cl.[7]: **H01S 5/10**

(21) Application number: **97301021.8**

(22) Date of filing: **18.02.1997**

(54) **A method and apparatus for improving the stability of a laser**

Verfahren und Vorrichtung zur Verbesserung der Stabilität eines Lasers

Méthode et dispositif pour améliorer la stabilité d'un laser

(84) Designated Contracting States:
DE FR GB

(30) Priority: **29.02.1996 US 60874**

(43) Date of publication of application:
03.09.1997 Bulletin 1997/36

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WO-A-96/00997

- **ELECTRONICS LETTERS, vol. 30, no. 25, 8 December 1994, pages 2147-2149, XP000502105 VENTRUDO B F ET AL: "WAVELENGTH AND INTENSITY STABILISATION OF 980NM DIODE LASERS COUPLED TO FIBRE BRAGG GRATINGS"**
- **ELECTRONICS LETTERS, vol. 22, no. 3, 30 January 1986, STEVENAGE GB, pages 134-135, XP002033196 E. BRINKMEYER ET AL: "fibre bragg reflector for mode selection and line narrowing of injection lasers"**
- **PROCEEDINGS OF THE CONFERENCE ON LASERS AND ELECTROOPTICS (CLEO) MAY 22-26 1995 BALTIMORE, MARYLAND, VOL 15 1995 TECHNICAL DIGEST SERIES, PAPER CTUF3, XP002033197 S.Y. HUANG ET AL: "Optical feedback induced degradations of teh spectrum and kink current of 980 nm pump lasers"**

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EP 0 793 314 B1

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Technical Field

[0001] This invention relates to the field of lasers.

Background of The Invention

[0002] In current laser technology, material(e.g. semiconductors, gas, solid-state materials) is positioned between two precisely aligned optical mirrors. One of the mirrors is nearly 100% reflective(e.g., 95%), and the other mirror is partially reflective (e.g. 1%, 5%). An outside source(e.g., and initial current) is used to excite the electrons of the material positioned between the two mirrors. As the electrons are excited, the electrons release light which reflects back and forth between the two mirrors. The two mirrors and the material positioned in between the two mirrors form a resonator that bounces the light back and forth. As the light bounces back and forth, light moving in the same aligned direction, is ejected from the cavity as a laser light.

[0003] When the material between the reflective mirrors is a semiconductor material, most of the unexcited electrons reside in an area known as the valance band. The valance band is a low energy state. As the electrons are excited they jump across an area known as the bandgap of the semiconductor to a region known as the conduction band. The conduction band is a high energy state. In the conduction band the electrons are in an excited state. When laser light is ejected from the resonator most of the electrons are located in the conduction band. In order for laser light to be ejected from the resonator, enough of the electrons have to leave the valance band and enter the conduction band. A higher population of electrons in the conduction band, than in the valance band is known as population inversion.

[0004] The energy of the light in the resonator can be described by wavelength or frequency. The relationship $\lambda \times E = hc$, defines the relationship between energy, wavelength and frequency, where E is energy, λ is wavelength, h is Planck's constant and c is the speed of light in a vacuum. However, when a semiconductor is used as a laser material, the speed of light is changed to the speed of light in that material. Therefore when a semiconductor is used, the laser is characterized by the ratio of the speed of light in a vacuum to the speed of light in the semiconductor material. This characteristic is known as the refractive index of the material.

[0005] As different wavelengths of light resonate in the cavity, the different wavelengths of light resonate at different frequencies. The light resonates over a range of frequencies or harmonics. Although most lasers will have a dominant frequency, a typical laser cavity will also have sub frequencies or harmonics of the dominant frequency, these harmonics are called Fabry-Perot(FP) modes. FIG. 1 displays a graph of the laser gain on the y-axis, versus the laser wavelength on the x-axis. In FIG. 1 a dominant frequency 2 and harmonics 4 are displayed. The peaks of the dominant frequency 2 and the harmonics 4 define the gain curve 6. The spacing between two frequencies of the laser is the Fabry-Perot spacing 8. A laser normally operates at one dominant frequency, such as the dominant frequency 2. However, operating conditions(e.g. laser drive current, temperature, external reflections) can cause a laser to switch from the dominant frequency, to one of the harmonic frequencies 4. The switching between modes (known as mode jump) causes the laser to be unstable.

[0006] Stability of the dominant frequency depends on the laser material, and the external reflection of laser light back to the laser cavity. For example, it has been found in lasers without a grating, that even small reflections of the output laser light back to the cavity, causes laser instability(see, S.Y. Huang, *"Optical-feedback-induced degradations of the spectrum and the kink current of 980-nm pump lasers"*, CLEO'95 Technical Digest, pp. 76-77, Baltimore, May 1995). As a result several techniques have been developed to handle laser instability due to reflections. One technique uses a device know as a fiber grating. A fiber grating is placed in the output light stream of a laser and coherently reflects the dominant frequency of the laser light back into the laser cavity. Therefore the grating enhances the dominant frequency of the laser light which in turn reduces instability. Normally, in a laser with a particular wavelength such as a 980nm pump laser, the fiber grating is designed so that the grating enhances the 980nm wavelength harmonic and suppresses any other harmonics. Therefore the wavelength that the fiber grating reflects is usually centered around 980nm. Most fiber gratings are usually designed to handle the specific dominant frequency of the laser, therefore the bandwidth of most fiber gratings is narrow. For a typical fiber grating, when the reflectivity(ability of the grating to reflect light) of the grating is plotted as a function of wavelength, the plot appears as a gaussian curve displayed in FIG. 2. In FIG. 2 the x axis represents the wavelength traversing the fiber grating and the y axis represents the reflectivity of the fiber grating at that wavelength. In addition, the line 10 is known as the full-width half maximum(FWHM) spectral width of the fiber grating. The spectral width is the wavelength range for which the fiber grating can reflect light. The FWHM is a measurement of the fiber grating, and is defined as the wavelength at which the rising pulse passes 50% of the peak reflectivity, to the wavelength at which the reflectivity drops below the 50% point.

[0007] The fiber gratings are used in conjunction with a laser (e.g., a semiconductor laser). Semiconductor lasers have active materials whose refractive index is a function of temperature. In order for a laser to be stable the output

optical power of the laser should be maintained constant against laser aging, ambient temperature change and mechanical stress. Therefore a feedback loop is often used in semiconductor lasers to try to maintain stability in the laser. An initial current provides initial energy which causes electrons and holes to inject into the conduction band and valance band, respectively, and produce population inversion. In some lasers a feedback loop is achieved by using a detector to detect small amounts of optical output power emitting from the rear of the laser (using a rear monitor) and feeding the power back into the initial current. As a result, a constant output power is maintained at the front of the laser. In order for this feedback control mechanism to work, the rear output power has to be linear over a certain current range. However, when current is injected into a semiconductor laser, part of the electrical power is converted into heat, resulting in an increase in the temperature of the laser material. As the semiconductor material increases in temperature the index of refraction of the material changes. The change of the index of refraction of the semiconductor material in turn shifts the dominant harmonic frequency of the laser. Therefore, as the current fed into the laser increases, the dominant harmonic shifts.

[0008] WO 96/00997 discloses a fiber grating used in conjunction with a diode laser for enhancing the dominant frequency of the laser light.

[0009] When a fiber grating is used with the semiconductor laser and the dominant frequency coincides with the grating mode the output power increases, and when the dominant harmonic moves away from the grating mode the output power decreases. This phenomena of switching between dominant harmonic modes is the mode jump discussed earlier. If the fiber light output power (L) and the rear monitor current (I_{bd}), is plotted as a function of the laser current (I), the mode jump shows up as undulation in the L vs. I curve 10 and I_{bd} vs. I curve 20 of FIG. 3. It would be advantageous to stabilize the laser, thereby diminishing the amount of undulation in both the L vs. I curve 10 and I_{bd} vs. I curve 20.

Summary of the Invention

[0010] The present invention discloses a method and apparatus for increasing the stability of a laser. A configuration is defined between a semiconductor laser and a fiber grating to stabilize such a laser, thereby reducing the undulation in the L vs. I curve and the I_{bd} vs. I curves. Specifically, a grating with a spectral width that is between about two to about four times larger than the FP spacing of the laser is defined, so that there is one dominant harmonic in the laser output, or during the transition from one dominant mode to the next dominant mode the front and rear output power is linear as the laser current drive increases. Decreasing the undulation is accomplished by increasing the bandwidth of the fiber grating so that the grating couples the laser output to produce a linear L vs. I curve. In the present invention, the full width half maximum spectral width of the fiber grating is set to between about .4nm to about .6nm for a 980nm laser with a Fabry-Perot spacing of .17nm.

Brief Description of the Drawings

[0011] The objects, advantages and novel features of the invention will be more fully apparent from the following detailed description when read in connection with the accompanying drawings wherein:

[0012] FIG. 1 displays a curve of the gain versus wavelength.

[0013] FIG. 2 displays the reflectivity curve of a fiber grating.

[0014] FIG. 3 displays a graph of the fiber light output .vs. the laser forward current, where the spectral width is less than 0.01 nm.

[0015] FIG. 4 displays the fiber light output .vs. laser forward current of the present invention, where the spectral width is 0.19 nm.

[0016] FIG. 5 displays the fiber light output .vs. laser forward current of the present invention, where the spectral width is 0.58 nm.

[0017] FIG. 6 displays a schematic diagram of the present invention.

[0018] FIG. 7 displays the front and back LI linearity as a function of the Fiber Grating Spectral Width.

Detailed Description of the Invention

[0019] In the architecture disclosed in the present invention, the spectral width of a fiber grating is made larger than the FP spacing of the laser cavity. As a result, even though there is mode jump in the laser output, the harmonics of the laser will fall within the bandwidth of the fiber grating. For example, in a 980 nm pump laser, the dominant frequency or mode would be centered at 980nm. The next harmonic of the dominant frequency may occur at 980.17nm, therefore the FP spacing for this laser is .17nm. When the spectral width of the fiber grating is increased to 0.19 nm which is 0.02nm larger than the FP spacing, the curve displayed in FIG. 4 occurs. The undulation in both the L vs. I curve 10 and the I_{bd} vs. I curve 20, decreases. When the spectral width of the fiber grating is increased to 0.58nm, which is 0.41nm larger than the FP spacing of the laser cavity, the undulation in the L vs. I curve and the I_{bd} vs. I curve are

diminished even further, as displayed in FIG. 5. It should be appreciated that the amount of decrease in the undulation of the L vs. I curve and the I_{bd} vs. I curve that is considered acceptable, is dependent on the specific application that the laser is being used for. However, many applications will require that the L vs. I curve and the I_{bd} vs. I curve are as smooth as possible. For example the present invention utilizes the laser as a pump source for an optical amplifier, therefore a fiber gratings with a spectral width that is about 3 times the FP spacing of the laser would be most desirable, since a fiber grating with a spectral width that is about 3 times the FP spacing of the laser, produces a straight L vs. I curve and I_{bd} vs. I curve. A control sample is lastly used to determine the FWHM spectral width needed for a particular FP spacing and a desired degree of undulation reduction.

[0020] The decrease in the undulation in the L vs. I curve and the I_{bd} vs. I curve results from using the spectral width of the fiber grating that is larger than the FP spacing of the laser cavity. As a result, the fiber grating can accommodate the transitions (mode jump) between the peaks of the different harmonics linearly. In other words as the laser transitions between the peak of one mode and the peak of another mode, the laser output light is still within the bandwidth of the fiber gratings spectral width. In previous grating configurations (e.g., where the spectral width of the fiber grating is < . 01nm) as the laser moved from one harmonic to another, the laser would move outside of the spectral width of the grating. As a result, the fiber grating would reflect light back to the laser cavity non-uniformly. In the method and apparatus of the present invention, when the spectral width of the fiber grating is greater than the FP spacing, as the laser cavity jumps from one mode to another, the transition between modes still falls within the bandwidth of the fiber grating. Therefore a constant uniform feedback of optical power is returned to the laser cavity, and a linear L vs. I curve results.

[0021] FIG. 6 displays an illustrative example of the apparatus used in the present invention. For the purposes of the invention, the laser such as a multimode laser should displays a Fabry-Perot mode. In FIG. 6 a semiconductor laser chip 100 is mounted in a laser carrier 110. The laser carrier 110 is composed of aluminum nitride or beryllium oxide. However, it should be appreciated that the laser carrier could be any material that displays a high thermal conductivity because one of the purposes of the laser carrier is to dissipate heat from the laser. In addition the laser carrier 110 should have an expansion coefficient that matches the laser chip so that there is less expansion stress in the laser chip. The laser carrier provides a vehicle support for the laser chip 100 and serves as a heat sink. Front light emission from the laser 100 is coupled to a single mode fiber 150 through a micro lens 140. The single mode fiber 150 is terminated with a beveled connector 170. Rear light emission of the laser 100 is monitored by a photodiode 130. The laser 100, the laser carrier 110, the photodiode 130, and the microlens 140 are all housed in a laser module 120. The laser module 120 has a height of 0.76 cm (.3 inches), a length of 2.54 cm (1 inch), and a width of 0.76 cm (0.5 inches).

[0022] A first order fiber grating 160 with a length of around 1cm is located about 12.7 cm (5 inches) to about 101.6 cm (40 inches) away from the laser chip 100. However, it should be appreciated that if the fiber has a smaller change of the index of refraction a longer grating should be used and conversely, if the fiber has a larger change of the index of refraction a shorter grating can be used. For example, the fiber grating 160 has the parameters given in table I:

TABLE I

Parameter	Min	Max	Unit
Grating Peak Reflectance	1	3	%
Center Wavelength	978	982	nm
Spectral Width(FWHM)	0.4	0.6	nm
Spectral Side Mode Suppression Ratio	10	---	dB
Temperature Tuning Rate	-0.02	0.02	nm/DEG °C

[0023] Utilizing a grating with the characteristics described in Table I, results in a more stable 980nm semiconductor laser. FIG. 7 displays the front and back light performance of the laser and grating used in the present invention. In FIG. 7, the spectral width of the fiber grating, are plotted as a function the first derivative change in optical power 200 (DL'/L') and the change in monitor current 210 (DI_{bd}/I_{bd}),. As detailed in the graph, as the spectral width increases, the change in optical power and monitor current decreases. For example, as the spectral width is increased from 0 to 0.2nm both the front light 200 and the back light 210, decrease drastically. Between the spectral width ranges of 0.2nm and .6nm, both the front light 200 and the back light 210 experience a gradual decrease.

[0024] While several embodiments of the invention are disclosed and described, it should be appreciated that various modifications may be made without departing from the scope of the subjoined claims.

Claims

1. A method of generating light from a laser (100), comprising the steps of:

   generating light from said laser wherein said light includes harmonics with Fabry-Perot spacing; and providing said generated light to a fiber grating (160)

   CHARACTERISED IN THAT the fiber grating has a spectral width three times greater than the Fabry-Perot spacing of the laser so that the output power of the laser is linear with respect to the laser current.

2. The method of claim 1 wherein the fiber grating is positioned between about 14 cm (5 inches) to about 103 cm (40 inches) from said laser.

3. The method of claim 1 wherein the fiber grating is a first order fiber grating.

4. The method of claim 1 wherein the fiber grating is about 1 cm in length.

5. The method of claim 1 wherein the laser has Fabry-Perot spacing of about 0.17nm.

6. The method of claim 5 wherein the fiber grating has a grating peak reflectance of between about 1% and about 3%.

7. The method of claim 5 wherein the fiber grating has a center wavelength between about 98 nm and about 982 nm.

8. The method of claim 5 wherein the fiber grating has a spectral width of about 0.4 nm to about 0.6 nm.

9. The method of claim 5 wherein the fiber grating has a side mode suppression ratio of greater than 10 dB.

10. The method of claim 6 wherein the fiber grating has a temperature rate of about -0.02 nm/DEG C to about 0.02 nm/DEG C.

Patentansprüche

1. Verfahren zum Erzeugen von Licht aus einem Laser (100), das folgende Schritte umfaßt:

   Erzeugen von Licht aus einem Laser, wobei das Licht Harmonische mit Fabry-Perot-Abstand enthält; und Liefern des erzeugten Lichts an ein Fasergitter (160),

   dadurch gekennzeichnet, daß das Fasergitter eine Spektralbreite aufweist, die um das Dreifache größer ist als der Fabry-Perot-Abstand des Lasers, so daß die Ausgangsleistung des Lasers relativ zu dem Laserstrom linear ist.

2. Verfahren nach Anspruch 1, wobei das Fasergitter in einem Abstand von zwischen etwa 14 cm (5 Zoll) und etwa 103 cm (40 Zoll) von dem Laser positioniert ist.

3. Verfahren nach Anspruch 1, wobei das Fasergitter ein Fasergitter erster Ordnung ist.

4. Verfahren nach Anspruch 1, wobei das Fasergitter etwa 1 cm lang ist.

5. Verfahren nach Anspruch 1, wobei der Laser einen Fabry-Perot-Abstand von etwa 0,17 nm aufweist.

6. Verfahren nach Anspruch 5, wobei das Fasergitter einen Gitterspitzenreflexionsgrad von zwischen etwa 1% und etwa 3% aufweist.

7. Verfahren nach Anspruch 5, wobei das Fasergitter eine Mittenwellenlänge zwischen etwa 98 nm und etwa 982 nm aufweist.

8. Verfahren nach Anspruch 5, wobei das Fasergitter eine Spektralbreite von etwa 0,4 nm bis etwa 0,6 nm aufweist.

9. Verfahren nach Anspruch 5, wobei das Fasergitter ein Seitenmodenunterdrückungsverhältnis von über 10 dB aufweist.

10. Verfahren nach Anspruch 6, wobei das Fasergitter eine Temperaturrate von etwa -0,02 nm/°C bis etwa 0,02 nm/°C aufweist.

Revendications

1. Procédé de génération de lumière à partir d'un laser (100), comprenant les étapes de :

génération de lumière à partir dudit laser, ladite lumière comportant des harmoniques à espacement de Fabry-Pérot ; et
fourniture de ladite lumière générée à un réseau de fibres (160)

CARACTERISE EN CE QUE le réseau de fibres présente une largeur spectrale trois fois supérieure à l'espacement de Fabry-Pérot du laser de façon à ce que la puissance de sortie du laser soit linéaire par rapport au courant du laser.

2. Procédé selon la revendication 1, dans lequel le réseau de fibres est positionné à entre environ 14 cm (5 pouces) et environ 103 cm (40 pouces) dudit laser.

3. Procédé selon la revendication 1, dans lequel le réseau de fibres est un réseau de fibres du premier ordre.

4. Procédé selon la revendication 1, dans lequel le réseau de fibres présente une longueur d'environ 1 cm.

5. Procédé selon la revendication 1, dans lequel le laser présente un espacement de Fabry-Pérot d'environ 0,17 nm.

6. Procédé selon la revendication 5, dans lequel le réseau de fibres présente une réflectance maximale de réseau comprise entre environ 1% et environ 3%.

7. Procédé selon la revendication 5, dans lequel le réseau de fibres présente une longueur d'onde centrale comprise entre environ 98 nm et environ 982 nm.

8. Procédé selon la revendication 5, dans lequel le réseau de fibres présente une largeur spectrale comprise entre environ 0,4 nm et environ 0,6 nm.

9. Procédé selon la revendication 5, dans lequel le réseau de fibres présente un rapport de suppression de mode latéral supérieur à 10 dB.

10. Procédé selon la revendication 6, dans lequel le réseau de fibres présente un coefficient de température compris entre environ -0,02 nm/°C et environ 0,02 nm/°C.

FIG. 1

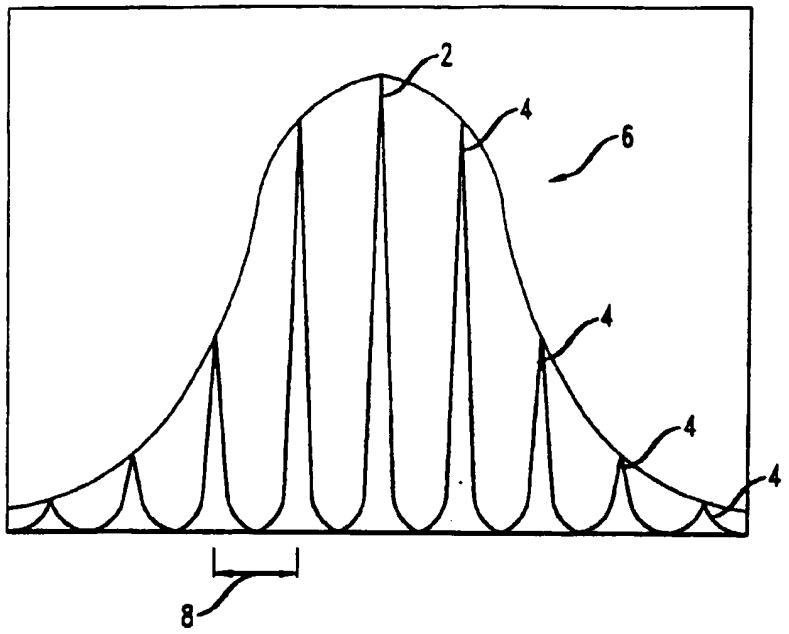


FIG. 2

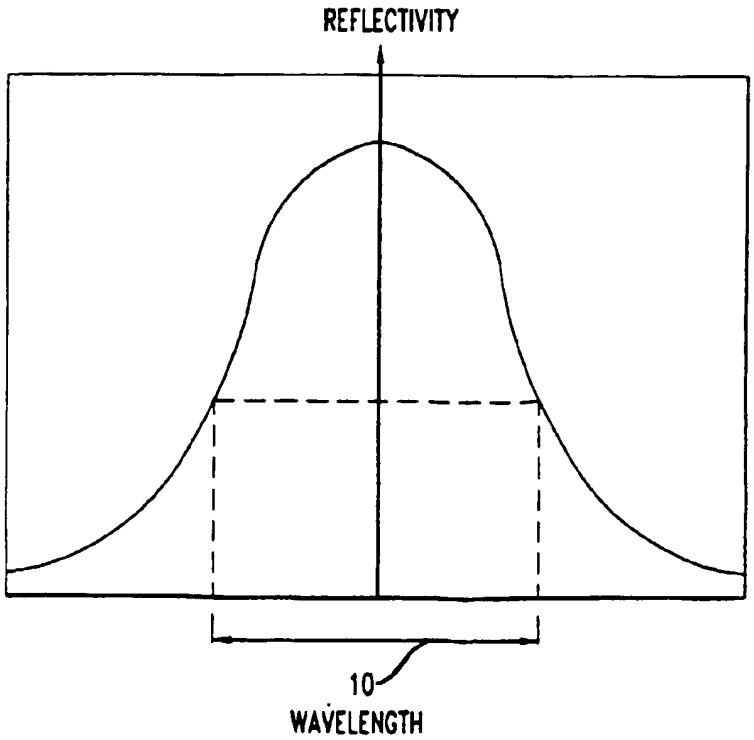


FIG. 3

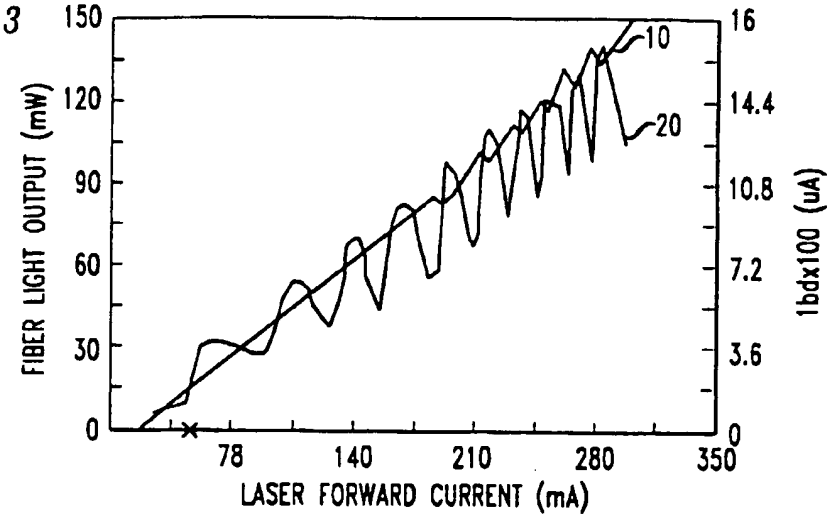


FIG. 4

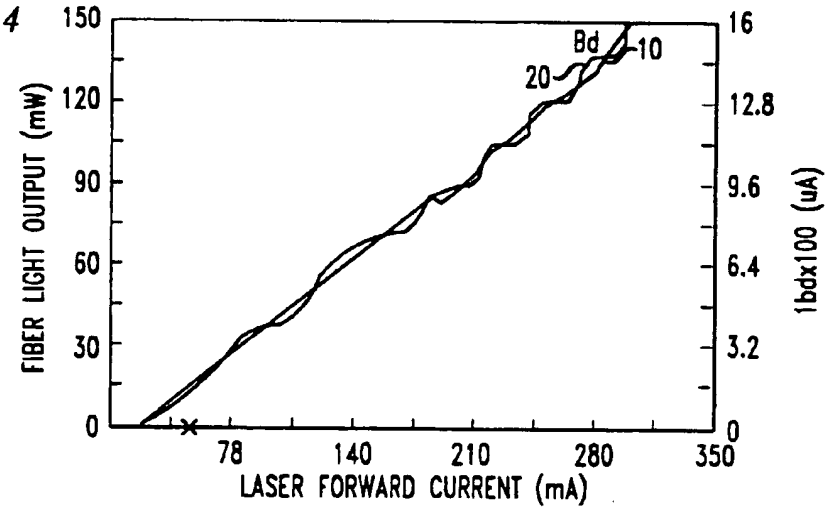


FIG. 5

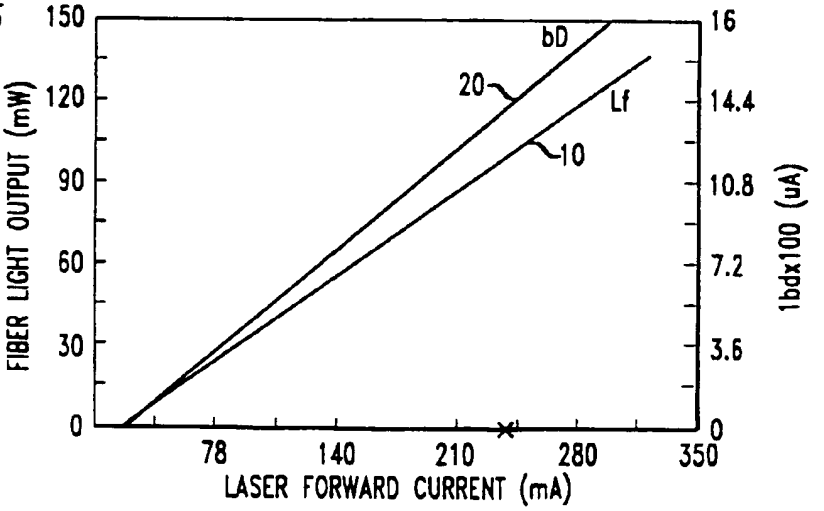


FIG. 6

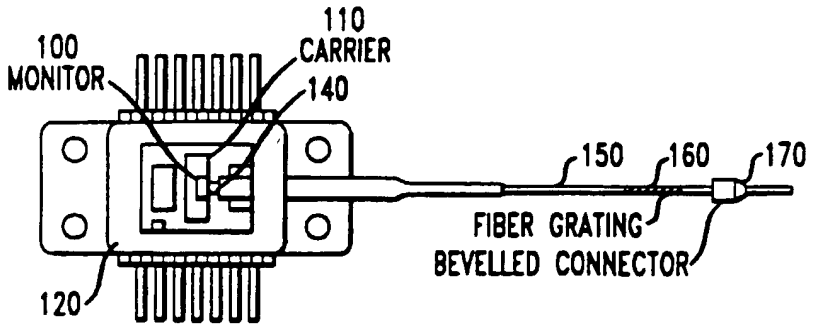
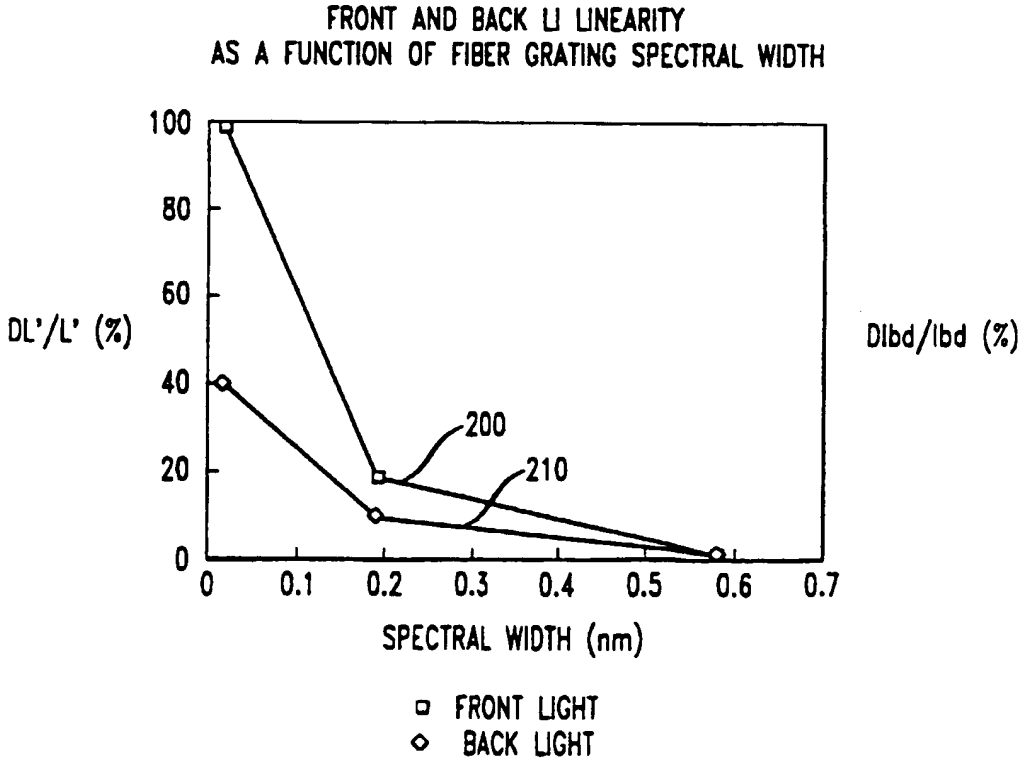

100
MONITOR
110
CARRIER
140
150
160
170
FIBER GRATING
BEVELLED CONNECTOR
120

FIG. 7


FRONT AND BACK LI LINEARITY
AS A FUNCTION OF FIBER GRATING SPECTRAL WIDTH
DL'/L' (%)
DIbd/Ibd (%)
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
SPECTRAL WIDTH (nm)
200
210
FRONT LIGHT
BACK LIGHT